California Energy Commission

DRAFT STAFF REPORT

PROPOSED VOLUNTARY CALIFORNIA QUALITY LIGHT-EMITTING DIODE (LED) LAMP SPECIFICATION

Proposed Voluntary Minimum Specifications for "California Quality" LED Lamps

CALIFORNIA
ENERGY COMMISSION

Edmund G. Brown Jr., Governor

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ABSTRACT

This *Proposed Voluntary California Quality LED Lamp Specification* ("Specification") staff report outlines a proposed voluntary quality Specification that would advise energy policy makers and the lighting industry in their collective goal to move consumers away from the inefficient incandescent lighting of the past century and toward the more efficient light-emitting diode (LED) lighting technology.

California Energy Commission staff worked with technical experts, utilities, and industry to determine the level of performance necessary to achieve a lighting product that would meet or exceed customer expectations for general purpose lighting. This Specification represents Energy Commission staff's proposed minimum requirements for an LED light to be considered "California quality."

The concept of the *California Quality LED Lamp Specification*, and many of the original arguments for its necessity, arose from discussions with Professors Michael Siminovitch and Konstantinos Papamichael, of the California Lighting Technology Center, and from ideas they developed in a report titled *Relighting American Homes with LEDs*, published as an editorial in *Lighting Design And Application*, August 2012.

This draft report will be used as the basis for discussion at a public workshop to be organized at the Energy Commission in late 2012. The workshop will solicit input from the lamp industry, the utilities, and other interested stakeholders, regarding the voluntary Specification. Staff will consider all comments received, and will develop a final report for publication.

Keywords: Light-emitting diodes, LED, LED replacement lamps, *Proposed Voluntary California Quality LED Lamp Specification.*

Lighting Terminology: There is lighting industry terminology used in this report for which some readers may not be familiar. Please see Appendix E for helpful definitions of some of the lighting terminology used in this document.

Flamm, Gary, Owen Howlett, Gabriel D. Taylor, 2012. ***Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification***. California Energy Commission, High Performance Buildings and Standards Development Office.

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EXECUTIVE SUMMARY

California Energy Commission staff worked with technical experts, utilities, and the lighting industry to determine the appropriate level of performance necessary to achieve a light-emitting diode (LED) lighting product that would meet or exceed customer expectations for general purpose lighting. The goal was to develop a voluntary quality specification that would inform energy policy makers and the lighting industry in their collective goal to move consumers away from the inefficient incandescent lighting of the past century and to the more efficient LED lighting technology. This *Proposed Voluntary California Quality LED Lamp Specification* (Specification) represents the Energy Commission staff's recommendation for minimum requirements an LED light should meet to be considered "California quality."

The *Proposed Voluntary California Quality LED Lamp Specification* applies only to LED lamps that are intended to be installed directly into incandescent luminaires ("light fixtures") as an alternative to incandescent lamps ("light bulbs"). As such, the Specification does not apply to many LED products that are now available on the market. For example, it does not apply to colored LED lamps, LED light strips, linear LED pin-based lamps, LED rope lights, LED fully integrated luminaires, LED luminaire housings, or LED light engines not having American National Standards Institute (ANSI) standardized screw-bases.

HistoryOn New Year's Eve, 1879, Thomas Edison gave his first public demonstration of his new invention, the electric filament lamp, at Menlo Park, New Jersey. Within four years there were more than 300 electric power stations in existence, feeding more than 70,000 incandescent lamps, each with an average life of 100 hours. This dramatic success established the "Edison screw" as the standard for residential light bulb sockets up to the present day.

In California there are now an estimated 530,000,000 general service "Edison Screw" lamp sockets in homes and places of work[1]. The majority of these sockets contain incandescent lamps that have not changed significantly from Edison's original filament lamp. Despite lighting codes promoting pin-based sockets in newly constructed buildings, screw-base sockets are expected to remain in the existing building stock for the foreseeable future. To meet California's energy policy goals, there is a need for consumers to have readily available high-efficacy screw-base lamps for these millions of existing Edison screw-base sockets.

Opportunity

Because LED lamps can now achieve comparable brightness and color quality to incandescent lamps, with instant-on and dimming capability, while using a fraction of the power, California is at the beginning of one of the largest energy savings opportunities in the history of the lighting market. The *2011 Integrated Energy Policy Report (IEPR)* recognized this and

1 http://www1.eere.energy.gov/buildings/ssl/tech_reports.html

recommended that “the Energy Commission and CPUC should collaborate to develop voluntary LED quality performance standards.”[2]

Need for a Voluntary Quality Specification

Most California consumers still choose the Edison electric filament lamp over Compact Fluorescent Lamps (CFL).See Chapter 1 below. For LED lamps to achieve significant market share, consumers must be confident that LED lamps can give them the light quality they need or want. This voluntary Specification would help accelerate demand by establishing LED performance criteria that reflect consumer expectations.

Though CFLs have improved steadily over the past decade, for many consumers, their opinions and perception of CFLs have been established by their experiences with poor quality early products. In the words of Ed Crawford, the head of the North American Lighting Division at Philips, the world's largest lighting company, “Some of the early compact florescent products, they were not ready for prime time. They buzzed, they had lousy color, and they made everything kind of grayish, green[3].” Early experiences with these lamps were enough to ruin consumer confidence in CFLs.. Though many products have improved their color properties, many consumers have not bothered to continue to seek out these lamps. The faltering satisfaction with CFLs has added to the challenge researchers face as lighting manufactures introduce LED lamps into the market and attempt to convince consumers that LED lamps can deliver the quality, performance, and efficacy that both consumers and designers want.

The slow and incomplete market adoption of CFLs in the residential market (compared to the commercial market) demonstrates that just because a product produces enough light, is cost-effective, and is supported by millions of dollars in persuasive marketing, the market adoption of that technology is not ensured. In 2006, just as CFLs sales beginning to increase (more than 20 years after they had been introduced), the U. S. Department of Energy commissioned a study of “lessons learned” from the introduction of CFLs[4]. Among its key recommendations:

- Manufacturers and energy-efficiency groups should coordinate to establish minimum performance requirements.
- Shift consumer focus from product price to product value.
- Delay launch rather than introduce inferior product; first impressions are long-lasting.
- Accurate incandescent equivalency on packaging is critical.

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2 California Energy Commission, 2011. *2011 Integrated Energy Policy Report*.
Publication Number: CEC-100-2011-001-CMF.

3 http://www.cbsnews.com/8301-3445_162-57344798/let-there-be-leds/?tag=contentMain;contentBody.

4 Department of Energy and Pacific Northwest National Laboratory, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*, June 2006,
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf.

A voluntary specification is a way of fulfilling the first two of these four recommendations. The third and fourth recommendations are beyond the scope of this specification.

At present, LED efficacy is not much higher than CFL efficacy for applications that involve omnidirectional light. In the short term, LED lamps that simply replicate the function of twister CFLs are unlikely to gain much market share, especially since they are typically $20-50 compared with $2-6 for a CFL. To gain market share and be seen as a high quality product worth the existing price differential, LEDs must provide performance that is measurably better than CFLs, such as dimming ability, higher color rendering, or more predictable color appearance.

The primary intent of this proposed Specification is to incentivize the market penetration of high quality LED lamps that meet customer expectations regarding performance and light quality. This Specification focuses on four quality attributes for LED lamps:

- Color quality
- Dimmability
- Longevity
- Light distribution

Cost and luminous efficacy are also important but are not the key priorities of this Specification. Cost is not discussed in detail in this report because the cost of compliant LED lamps cannot be known until the utilities negotiate volume pricing with the manufacturers. However, the report assumes that it will be possible for utilities to provide a rebate that reduces the cost of compliant lamps to a level at which consumers will purchase them in numbers large enough to influence the market. Luminous efficacy is not a priority because the energy use difference between high- and low-efficacy LED products is small; therefore a persistent and growing adoption of moderate efficacy lamps that meet consumer expectations will provide significantly more energy savings than a limited adoption of the highest efficacy lamps.

Status and Use of This Specification

This Specification is intended to serve as a resource for the California investor-owned utilities and other entities when purchasing LEDs for incentive programs or for construction projects. It supports the goals of the State of California and the California Energy Commission by conserving energy, both up to and beyond 2018 (when major changes will take place to lighting standards in California). This specification does not establish a framework for the California Energy Commission to certify or take enforcement action in regard to LED lamps.

CHAPTER 1:
Lessons From the Introduction of Compact Fluorescent Lamps (CFLs)

Efforts to move California homes to high-efficiency light sources have been underway since at least 1992, when California utilities launched full-scale CFL rebate programs.

In California, 21 percent of all residential lamp sockets are now fitted with CFLs, and 29 percent of all medium screw-base sockets (residential plus nonresidential) are fitted with CFLs[5,6]. While this compares favorably with the national average of 11 percent of residential sockets[7], it is a low rate of penetration compared to the size of the full market potential of the technology. From 2004-2008, 30 percent of screw-based lamps sold in California were CFLs[5], indicating that the market share may have stabilized. Because CFLs have a longer rated life than incandescent lamps, a market share of 30 percent should result in more than 30 percent of sockets being fitted with CFLs, so these numbers suggest that the number of installed CFLs may still be increasing; nevertheless, evaluators have speculated that the residential CFL market has reached saturation. Tthat is to say, current CFL owners have bought as many CFL lamps as they ever intend to and are simply replacing the CFLs in their home as they burn out. New consumers are not switching from incandescent lamps to CFLs at a significant rate.

Market adoption of CFLs has been slower and less complete in California than in the Northwest (where incentives were lower), and much slower and less complete than in other industrialized countries[8]. These statistics raise the question of why California's 20-year effort to promote CFL lamps was not more successful, and what can be done differently to achieve more success with LED lamps. A comprehensive attempt to answer this question was made by the U. S. Department of Energy in 2006[9].The DOE report suggests a number of lessons from the CFL market effort that should be learned before the widespread promotion of LED lamps (See Appendix E).

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5 The Cadmus Group and Quantec, *Compact Fluorescent Lamps Market Effects Final Report* (California Public Utilities Commission, Energy Division, April 12, 2010), http://www.calmac.org/publications/CFL_ME_Final_Report_04-12-10_3.pdf.

6 At the time of writing, the penetration of LED lamps has not been measured by any study as being more than 1 percent, that is, too low to evaluate.

7 Department of Energy, "CFL Market Profile 2009", March 2009, http://www.energystar.gov/ia/products/downloads/CFL_Market_Profile.pdf.

8 ECOS Consulting, *Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets? Volume 1: Strategies and Recommendations.* (Natural Resources Defense Council, n.d.).

9 Department of Energy and Pacific Northwest National Laboratory, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*.

Price

Price has consistently been identified by program evaluations as the main factor in market adoption, and indeed CFL market penetration over time has correlated closely with price reductions. However, the average retail price of a CFL has been under $2 per lamp since 2004[5], yielding a payback period of less than one year[10]. This shows that, even with a very fast payback, many consumers are not willing to use CFLs for the majority of lighting in their homes. Cost-effectiveness may be necessary for market adoption, but has not been sufficient to increase the market share of CFLs to the level of incandescent lamps.

Consumer Preference

Most of the effort spent on promoting the adoption of CFLs in the market, has been aimed at reducing their price to be comparable with incandescent lamps. In comparison, the amount of effort and research spent on understanding what product characteristics consumers wanted, and whether and how CFLs should be improved, has been very small.

In California, consumer preference studies have been limited to telephone surveys and shopper-intercept surveys. While these studies are useful in understanding consumers' decisions to purchase one lamp over another in a given transaction, they do not provide enough depth to reveal the reasons why consumers make the decision to purchase or not purchase CFLs in the long run.

In fact, the studies conducted in California have indicated that consumers have had a consistently *high* opinion of CFLs since the beginning of utility incentive programs, and that a majority (81 percent) of consumers would like to use either CFL or LED lighting rather than incandescent as their preferred lighting solution[11]. These findings are clearly at odds with the fact that CFLs have not achieved wider acceptance, which suggests that the surveys used to date have been unsuccessful in accurately identifying areas for product or marketing improvement. This is not surprising in the context of the general inaccuracy of consumers' self-reported behavior. For instance, a study by Energy Market Innovations[12] found that consumers were not even aware of how many CFLs they had in their home (they underestimated the number of lamps by more than 40 percent). The same study found that consumer estimates of how many CFLs they would install in their home varied by a factor of three, depending on whether they were asked the question on a written survey or asked in person by a utility representative.

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10 U.S. Department of Energy, "CFL Market Profile 2009."

11 EcoAlign, *EcoPinion+Lighting+Survey+Report+10+vf.pdf*, EcoPinions, March 30, 2010, http://www.ecoalign.com/system/files/EcoPinion+Lighting+Survey+Report+10+vf.pdf.

12 Energy Market innovations, *Puget Sound Area Residential Compact Fluorescent Lighting Market Saturation Study* (Puget Sound Energy, n.d.), http://www.emiconsulting.com/assets/pdf/CFL%20Saturation%20Study.pdf.

The few in-depth studies on consumer purchasing and use of CFLs conducted in the United States have shown that consumers are much less satisfied with CFLs than is suggested by the many telephone surveys and shopper-intercept studies that have been conducted as part of IOU program evaluations. A thorough in-home study conducted by the Lighting Research Center[13] found that among consumers who said that they were "satisfied" with CFLs, only 60 percent said that the color of the lamps was satisfactory, and among those who were not satisfied, 57 percent thought the color was satisfactory.

ENERGY STAR®

ENERGY STAR performance criteria for CFLs was introduced in 1999 and revised in 2001 and 2003. The performance criteria include correlated color temperature, color consistency (MacAdam ellipses – defined in Appendix A), and color rendering. Although it is not possible to establish that the ENERGY STAR performance criteria were responsible for the strong increase in CFL sales around 2004, CFL sales surged after the introduction of the ENERGY STAR performance criteria (see Appendix C).

Lamp Life

Consumer surveys have found lamp life to be a comparatively minor complaint among CFL purchasers, and the only quantitative study of CFL returns (that is, consumers returning CFLs to a store due to early failure) found only 47,000 returns from 2.1 million product sales (2.2 percent). However, lighting experts consistently complain about the unpredictable and sometimes short life of CFLs. Therefore, lamp life remains an under-researched and unsolved question.

One early evaluation of the CFL market[14] paints a telling picture of both consumers' and evaluators' perceptions. The evaluation focused on whether consumers understood the advantages of CFLs. They were asked how long a CFL lasts, and most guessed that it was between two and five times as long as an incandescent lamp, whereas the "correct" answer (as deemed by the evaluators) was "more than ten times as long." Given the many anecdotal reports of short CFL life outside the laboratory environment, the consumers were probably closer to the real answer than the evaluators.

The failure of CFLs to meet their claimed lamp lifetimes in practice may be one of the important underlying reasons why consumers have become disillusioned with CFLs. Many CFLs failed to

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13 Lighting Research Center, *Increasing Market Acceptance of Compact Fluorescent Lamps* (U.S. Environmental Protection Agency, September 30, 2003), http://www.lrc.rpi.edu/programs/lightingTransformation/colorRoundTable/pdf/MarketAcceptanceOfCFLsFinal.pdf.

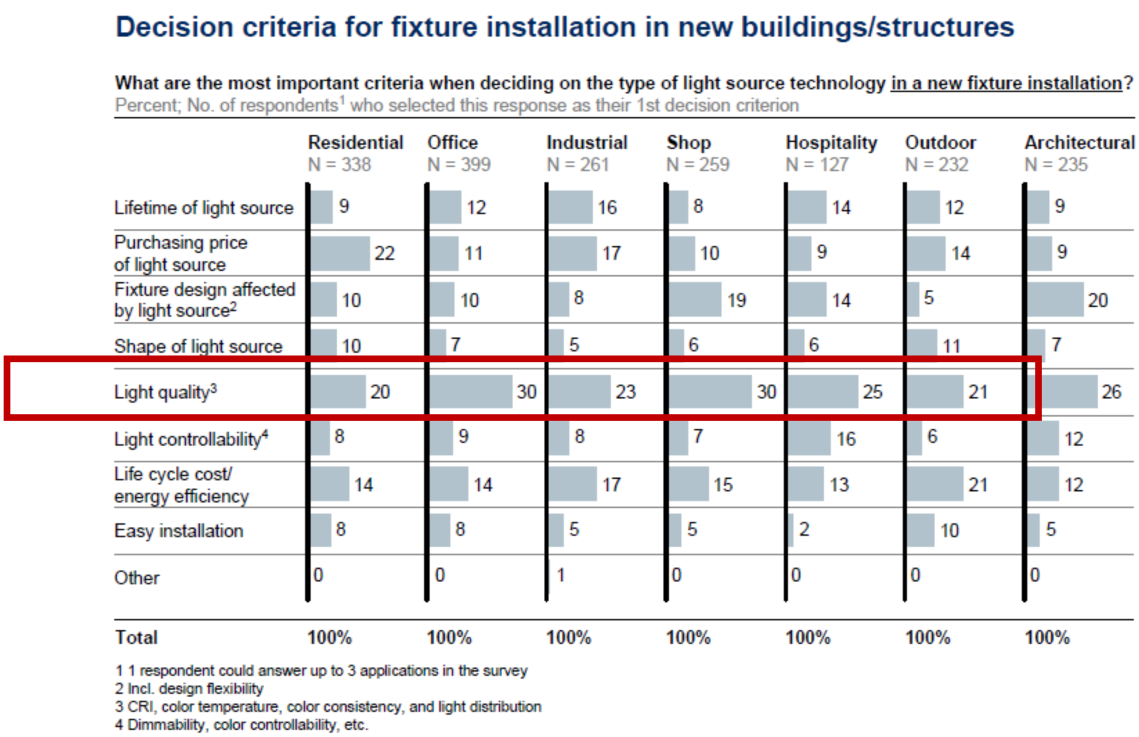
14 Decision Sciences Research Associates, *Residential Lighting Market Transformation Study*, September 1998, http://www.calmac.org/publications/19980901SCE0003ME.PDF.

deliver longevity because of heat-related failure of the electronics that drive them, such as in downlights with vertical sockets that trap heat in the area of heat-sensitive electronics.

Summary of Lessons Learned From CFLs

Energy Commission staff believe that the introduction of CFLs to the residential market has been disappointing primarily due to consumer dissatisfaction with color quality (color rendering, color consistency), lack of dimming capabilities, and unpredictable lamp life of CFLs. Recent research, such as that from McKinsey's 2011 *Lighting the Way* report, suggests that consumer lighting purchase decisions are driven as much by light quality, as they are by the cost of the light bulb. As shown in the figure below, 20 percent of residential respondents rated light quality as the most important decision criterion for lamp installation – which is on par with the 22 percent who rated purchase price as the most important factor. In all other market segments, light quality was by far the most important factor. A similar recent study found that "quality of light" was the most important of eight lamp attributes[15], and that 67 percent of consumers were in favor of phasing out incandescent lamps over time (with 21 against, and 13 percent undecided).

Figure 1: McKinsey Study, *Lighting the Way*[16]



Source: McKinsey Global Lighting Professionals & Consumer Survey

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15 Other attributes were overall performance, energy efficiency, price, ease of use, maintenance, appearance/color, and disposal.

16 McKinsey & Company. *Lighting the Way: Perspectives on the Global Lighting Market*. July 2011.

CHAPTER 2: Attributes of the Proposed Voluntary California Quality LED Lamp Specification

The *Proposed Voluntary California Quality LED Lamp Specification* is built upon an "ENERGY STAR Plus" approach, designed to enable manufacturers to voluntarily meet the Specification and, in parallel, achieve ENERGY STAR certification for those same lamps.

The Voluntary California Specification uses the same efficacy requirement as the ENERGY STAR standard, and refers to the same test procedures, to make compliance as easy as possible. However, there are six key quality attributes in the proposed Specification that exceed those specified in ENERGY STAR:

- Color appearance
- Color consistency
- Color rendering
- Dimmability
- Longevity
- Light distribution

This section provides context on each of these attributes, including the metric used to quantify them and the standard performance typically exhibited by other lighting products and/or demanded by consumers.

See Appendix A for a comparison of the proposed Specification to the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

Color Appearance

The color appearance of a light source describes the apparent color of the light coming from the lamp. This color is associated with a unique location on a "chromaticity diagram", which shows all the possible colors of a light source. The axes of the color space are the CIE[17] x and y chromaticity coordinates; these are mathematical constructs used to describe color.

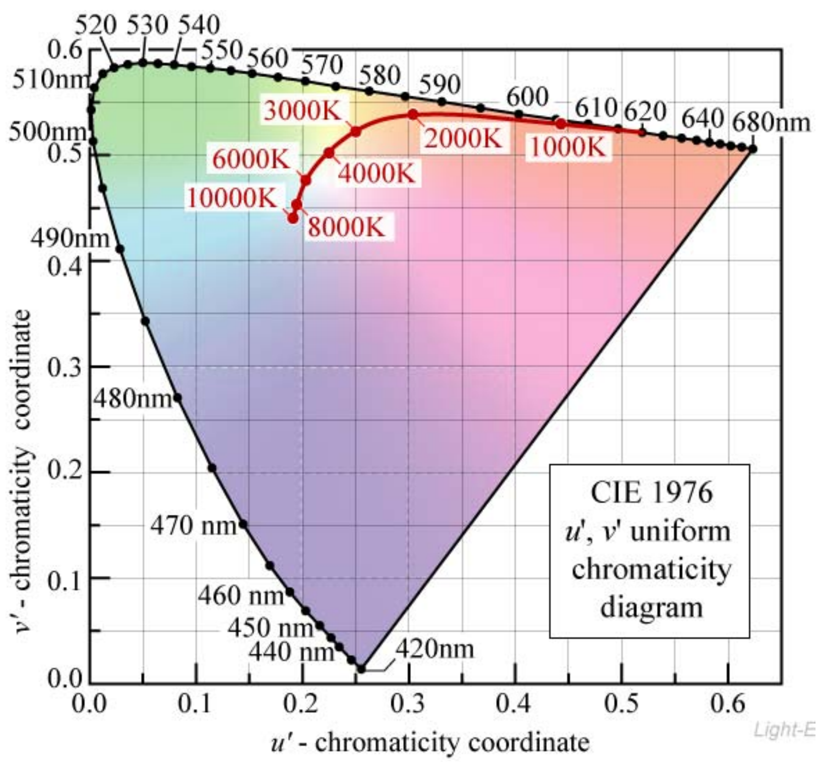
The color of incandescent lamps falls on the "Planckian Locus," which represents the range of colors of a theoretical "black body" or perfect emitter, when heated to various temperatures (measured in degrees Kelvin). Figure 2 demonstrates the 1976 CIE chromaticity diagram, and the curved black line represents the Planckian Locus. At the right end of the locus are "warmer" lamps with lower color temperatures, while at the left end are "cooler" lamps with higher color temperatures. Note the counterintuitive use of "warmer" for lamps with *lower* temperatures.

[17] Commission Internationale de l'Eclairage, the international body that sets underlying standards for the measurement of light and color.

Unfortunately, lamps such as fluorescents and LEDs do not usually lie exactly on the Planckian Locus. Lamps that lie above the locus have a green tint, while lamps below the locus have a pink or purple tint. Their deviation from the locus gives rise to the concept of "correlated color temperatures" (CCT), that is, the nearest point of the Planckian Locus to the chromaticity coordinate of the lamp. The lamp's chromaticity coordinate can be linked to its CCT point on the locus by lines that run roughly perpendicular to the locus. These CCT lines are shown in Figure 2.

Most general service lamps have color temperatures between 2500K and 6500K (degrees Kelvin), and different CCTs are appropriate for different applications; so there is no "ideal" CCT. That said, most consumers are used to about 2700K to 3000K in their homes because incandescent lamps at these color temperatures have been the predominant residential light source for many decades. Therefore, this Specification assigns two specific color temperature ranges, which will make compliant LEDs consistent in color with most of the other light sources in people's homes.

Figure 2: 1976 CIE u,v Chromaticity Diagram



Note: the red line shows the black body (or "Planckian") locus; the black line shows the spectral (monochromatic) colors.

Source: www.lightemittingdiodes.org, Chapter 18.[18]

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18 Fred Schubert, "Light-emitting diodes-dot-org Home Page," *Www.lightemittingdiodes.org*, 2006, http://www.ecse.rpi.edu/~schubert/Light-emitting diodes-dot-org/.

Color Consistency

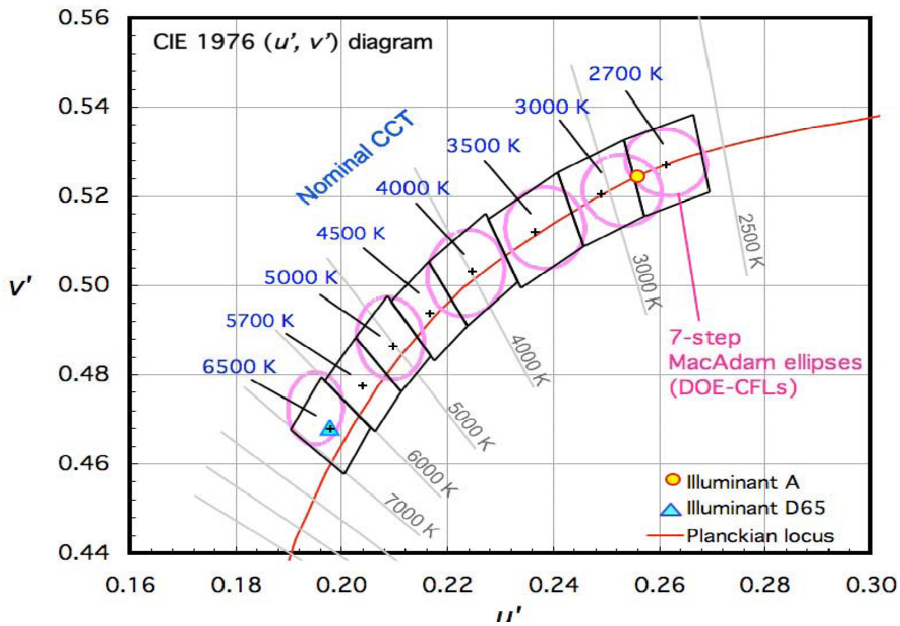
One of the challenges in the manufacture of LED lamps is to generate lamps of a consistent color without noticeable variations between lamps in the same batch, or between one batch and another.

The human eye is very good at discriminating even small light color variations between lamps; so to ensure consumer satisfaction with LED lamps, the proposed Specification addresses lamp color with the goal of ensuring color consistency among lamps of a given nominal CCT. The intended result is to ensure that if consumers buy two lamps marketed as 2700K (whether from the same manufacturer or not), they should be able to install them in the same room without noticing a difference between their colors.

To achieve this, limits need to be placed on the ranges of allowable color bins (rectangular regions of the chromaticity chart, as shown in Figure 3 below). The system used to describe the size of these bins is named after David MacAdam, whose research in the 1930s and 1940s led to an understanding of the amount of color change, starting from an initial point in the color space, which was indistinguishable to the average human eye. Because these shapes were ellipses in the color space, they are now commonly known as MacAdam ellipses. An observer is typically able to tell the difference between the color appearances of lamps that are one MacAdam ellipse apart.

As shown in Figure 3, the current American National Standards Institute ANSI standard for LED color binning, ANSI C78. 377, 2008, contains a specification for a 7-step ellipse (meaning that lamps with very different color appearances can be claimed to be of the same CCT). In the diagram below, pink ovals have been used by CFL manufacturers, while the black shapes represent 7-step Macadam ”quadrangles” for use by LED manufacturers.

Figure 3: ANSI Standard 7-Step MacAdam Ellipse



Source: ENERGY STAR Program Requirements for Integral LED Lamps.[19]

A research project conducted by the Lighting Research Center[20] indicates that somewhere between two-step and four-step MacAdam ellipses would be a suitable tolerance bound for LEDs, depending on whether the lamps are viewed directly adjacent to each other (two-step ellipses) or whether illuminated patches of wall are viewed without the lamp being visible (four-step ellipses). Further human factors research and product testing are being done in 2012 by the California Lighting and Technology Center to identify and support the color consistency requirements being considered as part of this Specification. Based on initial assessment of available products, manufacturer claims, and the noted rate of improvement for color consistency, the proposed Specification requires a significantly tighter bin than the ENERGY STAR requirements, but is likely not approaching the limits of human perception.

Color Rendering

Color rendering is a measure of how true the colors of objects look under a light source, as compared to how they look under a reference light source of the same (or similar) color temperature: The two most common reference sources are an incandescent lamp at 2700K and a typical spectrum of daylight at 6500K (known as "D65").

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19 "ENERGY STAR® Program Requirements for Integral LED Lamps" (U.S. Department of Energy, n.d.), http://www.energystar.gov/ia/partners/manuf_res/downloads/IntegralLampsFINAL.pdf.

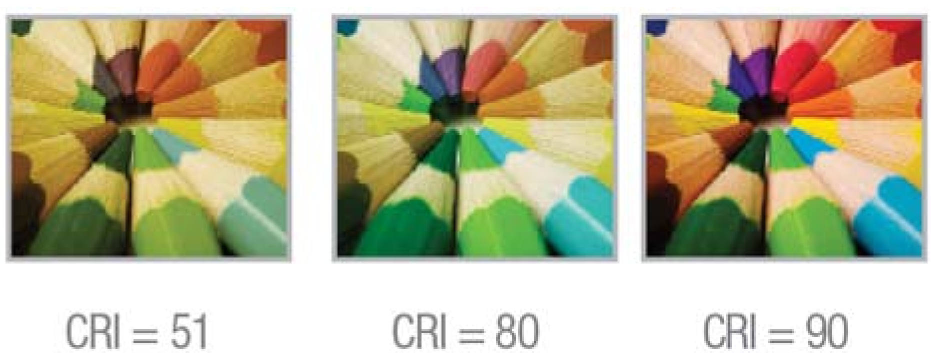
20 Nadarajah Narendran, Lei Deng, and Jean Paul Freyssinier, *Developing Color Tolerance Criteria for White LEDs* (Lighting Research Center, January 2004), http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/ColorDiscriminationStudy.pdf.

The most common metric of color rendering is the color rendering index (CRI). A CRI of 100 indicates that a light source renders a particular palette of eight colors in exactly the same way as the reference light source to which it is being compared. A light source with a CRI significantly less than 100 typically makes one or more of the eight standard palette colors appear more gray (less saturated) than the reference source, although a low CRI can also arise because a light source renders certain colors as being *too* saturated. An incandescent lamp is considered the ”reference” light source for low color temperature light, so by definition incandescent lamps achieve a CRI of 100.

It is important to realize that color rendering is *not* a measure of “naturalness” or “saturation” or “quality”. The CRI metric was developed for industrial purposes, when color checking was carried out by human observers, to prevent observers confusing one color with another (“metamerism”), rather than being optimized to make colors appear natural or colorful. Other metrics have been, and continue to be explored to quantify the naturalness of light sources, though none has replaced CRI as the primary metric. In particular, the National Institute of Standards and Technology (NIST) is continuing work on the Color Quality Scale (CQS), though we are not aware of any specific schedule for development of a new metric

The images in Figure 4 demonstrate the difference between low CRI and high CRI. In the picture on the left, which represents a 50 CRI light source, the pink, red, and orange pencils are hard to distinguish from one another. In the image on the right, representative of a 90 CRI light source, the colors are much more easily distinguished. (These images are for illustration only and should not be taken to accurately represent the actual appearance of objects.)

Figure 4: Comparison of Color Rendering Index of Different Light Sources



Source: Lighting Matters’ LED Blog, lightingmatters.com.au/blog/ledlight-quality-cri/

In addition to quoting CRI, LED manufacturers have begun to quote the performance of their products in terms of how they render a ninth color (“R9”—a saturated red color). This is, in part, because this indicates improved rendition of skin tones and vibrant red colors, but also because manufacturers wish to distinguish “good” LEDs from “bad” LEDs, and from typical triphosphor T8 lamps, which do not render the R9 color well. Typically the R9 value for T8 lamps is 10-20, whereas LEDs can achieve over 50.

As CFL program evaluations did not identify color as a key factor, improved color performance was not demanded or encouraged and was therefore abandoned in favor of lower cost.

Innovation and new investment in color were hard to justify and largely not pursued by mainstream manufacturers.

However, color rendering has become a more widely discussed lamp attribute, and some manufacturers in the blossoming LED lamp industry are already striving for improved CRI in their products. As of May 30, 2012, the U. S. Department of Energy's SSL Lighting Facts product database contained 123 replacement lamp products with a CRI of 90 or better. Because the LED market already includes a large number of products with high CRI, and because color quality has been identified as a key opportunity for improvement, the proposed Specification includes a minimum requirement for color rendering index.

Dimmability

One of the performance attributes of incandescent lamps expected and taken for granted by consumers, is that they are all readily dimmable over their full range of output without flicker. Consumers expect this attribute when they screw incandescent lamps into these sockets, and do not need to search for incandescent lamps that are specially labeled as "dimmable" when purchasing lamps. If LED lamps fail to meet this high standard of dimming performance, consumers are likely to be dissatisfied.

A significant number of existing incandescent sockets are already controlled with dimmer switches. DOE's *2010 Lighting Market Characterization* study found that 12 percent of residential sockets in the United States are controlled by dimmers[21]. This number is likely to be higher in California; a 2008 study of residential newly constructed buildings found that 29 percent of screw-based sockets were attached to dimmers (Wilcox 2008). The number of dimmable sockets is increasing quickly due to the state's aggressive *Building Energy Efficiency Standards, Title 24, Part 6* (the *Building Energy Efficiency Standards*). Starting with the 2005 residential lighting requirements of the *Building Energy Efficiency Standards*, many rooms in newly constructed residential buildings, additions, and alterations are required to install either high-efficacy lighting or incandescent luminaires controlled with dimmer switches. The *Building Energy Efficiency Standards 2008*, which are updated every three years, now require most screw-base sockets in residential newly constructed buildings to be on dimmer switches.

Indeed, it is not just in the residential sector that California is moving toward dimmable controls on all incandescent lighting. For many years, the *Building Energy Efficiency Standards* have required nonresidential buildings to have multilevel lighting controls on all types of lighting. Typically this could be accomplished with "checkerboard" switching (that is, switching some luminaires off in a checkerboard pattern), or with dimming. Starting with the 2013 update to the *Building Energy Efficiency Standards*, all incandescent lighting in nonresidential buildings will need to be fully dimmable, from 10 percent to 100 percent.

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21 Navigant Consulting, *2010 U.S. Lighting Market Characterization* (U.S. Department of Energy, January 2012), http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

Compatibility between lamps and dimmer controls is another major issue of concern because consumers expect lamps to be compatible with existing dimmers. Some LED lamps may experience flicker or cause dimmers to make noise, or simply not work on certain existing residential dimmers. To have both dimmable and nondimmable LED lamps available on the market, or "dimmable" lamps that are incompatible with most residential dimmers, runs the risk of further confusing and disappointing consumers.

The proposed Specification requires LED replacement lamps to be dimmable using the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (See Appendix A). The proposed Specification will also consider a dimmer switch compatibility protocol, pending the results from dimmer testing underway in 2012..

When incandescent lamps are dimmed, they become redder, or "warmer," but LED lamp manufacturers continue to wrestle with providing color shift for dimmed LED lamps as an added amenity, to satisfy consumer expectations. Future iterations of the proposed Specification may address this issue.

Longevity

As with CFLs, LED lamps are sensitive to heat, and their life is reduced significantly when they operate in hot environments or when heat generated by the lamp is not successfully removed from the diode junction. This voluntary *LED Lamp Specification* therefore addresses heat issues for all possible residential applications, and refers to appropriate test methods. This is particularly important in the context of insulation-contact, airtight (ICAT) recessed can luminaires (required by the *Building Energy Efficiency Standards*) and luminaires where the lamps are inside an enclosed diffuser; in both of these cases, heat from the LED builds up inside the fixture.

There is a current test procedure for lumen maintenance over time (IES LM-80), and there is an industry standard method for projecting lumen maintenance beyond the end of the testing period (IES TM-21). These methods allow manufacturers to calculate "L50" and "L70" values, which are the number of burn hours before the light output of a sample of LEDs reduces to 50 percent or 70 percent (respectively) of their initial values. These test methods are widely used by the LED industry, but the methods and their reference documents are in their first generation and there are several issues that require clarification and standardization, such as whether LED failures are included in the light depreciation figures for L50 and L70 tests. For instance, a lamp with an L70 of 50,000 hours may still fail either suddenly or steadily long before 50,000 hours of operation.

Future revisions of this S*pecification* will investigate industry test methods that may be under development, and which may help resolve this question. In the meantime, the *LED Specification* proposes to require both a minimum lumen maintenance value, as well as a minimum warranty, and to use the adverse heat environment specified in ENERGY STAR for lumen maintenance tests.

The proposed Specification will use the lamp life requirements currently listed in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (See Appendix A.) The purpose of specifying lamp life in this *Specification* is that there have been significant variations in the lamp life requirement in the various drafts of ENERGY STAR, so we cannot be sure that the final version of ENERGY STAR will include a high lamp life requirement.

Light Distribution

There are many LED lamps today that are marketed as "omnidirectional" but perform optically more like a directional lamp than an omnidirectional lamp. In other words, they provide very little side light and virtually no downlight. When such lamps (identified as "semidirectional" and "nonstandard light output" by ENERGY STAR) are installed in a typical table base-up lamp, virtually all of the luminous flux is directed at the ceiling. These lamps do not perform in the way consumers expect.

To ensure that LED lamps will perform according to consumers' expectations, this Specification distinguishes between three broad types of light distribution:

Omnidirectional Lamps

These lamps emit light almost equally in all directions, that is, over a complete sphere. They are sometimes used in portable luminaires such as "table lamps," as well as in many other luminaires that use shades. They are also used in luminaires that use diffusers, such as ceiling-mounted diffusing glass domes. General service incandescent lamps provide an omnidirectional distribution of light. In other words, when a general service incandescent lamp is screwed into a portable luminaire, the light is projected in all directions including upward onto the ceiling, sideways on to the lamp shade, and to a lesser extent downward on to the table. Many LED lamps that are being classified as general service LED lamps today project very little light to the side, and almost no light downwards. It is critical that consumers have omnidirectional lamps that meet their expectations and provide the same distribution of light as the incandescent lamps they are replacing. The proposed Specification will not recognize "semidirectional" or "nonstandard light output" lamps as being omnidirectional lamps.

The proposed Specification will use the omnidirectional lamp specifications in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A).

Floodlamps

These lamps emit no light "backward" toward the lamp base, but emit forward light somewhat evenly over a hemisphere. They are mostly reflector lamps such as reflector lamps that are 30/8 inch in diameter (R-30) and parabolic aluminized reflector lamps that are 38/8 inch in diameter (PAR 38), and are ideal for use in recessed downlights. In most recessed downlights, if omnidirectional lamps are installed, much of the available light gets trapped inside the downlight, reducing the overall efficiency of the lighting system.

The proposed Specification will use the directional lamp requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A), except for the "luminous intensity distribution" requirement. This is because the luminous intensity distribution requirement in ENERGY STAR is intended to accommodate spotlights, whereas the first version of the proposed Specification specifically excludes spotlights.

Spotlights

This Specification does not currently include a numerical definition for "spotlight", but this verbal definition is included to distinguish spotlights from floodlamps.

Spotlights have narrower beams than floodlamps and are intended to illuminate objects at a distance. They are typically used for outdoor lighting and in directional luminaires used to illuminate wall displays, art, plants or other objects of interest.

Retail lighting systems are commonly made up of directional lamps to create contrast illuminance on merchandise.

Lamps that fulfill these requirements will have a light distribution (beam angle) that is too narrow to meet the light distribution requirements for a "floodlight" defined in the proposed specification. They therefore cannot meet this version of the Specification.

CHAPTER 3: Proposed Voluntary California Quality LED Lamp Specification

Following are the minimum requirements for the *Proposed Voluntary California Quality LED Lamp Specification*. The Specification is intended to be "ENERGY STAR plus delta", that is, the Specification simply refers to the ENERGY STAR requirements when those are sufficient for this Specification. However, in some cases alternative or additional requirements are made. These requirements are consistent with the ENERGY STAR standards as much as possible; that is, they draw on the same data or use similar metrics.

A comparison of the specifications required for the proposed Specification and the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 is shown in Appendix A.

Eligible Lamp Bases and Lamp Shapes

Figure 5 shows which combinations of LED lamp bases and lamp shapes are eligible for this specification. Each cell of the table shows which light distribution(s) are allowed for that particular combination of lamp base and shape.

Figure 5: Eligible Lamp Bases and Lamp Shapes

		Lamp shape					
		A,G, B,BA,C,CA,F	R,BR,	MR	PAR20, PAR30,	PAR38	JC Bi-pin, wedge
Lamp base	E12, E17, E26, GU-24 (120V)	Omnidirectional	Floodlamp	X	Spotlight	Spotlight or Floodlamp	X
	GU-10 (120V)	X	X	Spotlight	Spotlight	X	X
	GX5.3 (12V)	X	X	Spotlight	X	X	X
	G8, G9 (120V)	X	X	Spotlight	X	X	Omnidirectional

Also, LED luminaires that are designed to be retrofitted within existing cylindrical recessed can housing, and which contain one of the lamp bases listed above, are eligible.

LED lamps must be classified as either “omnidirectional” “floodlamps”, or “spotlights”; this Specification does not recognize any other types of lamp.

To be classified as “omnidirectional”, lamps must meet the following criteria:

- The lamp shape must be A or G.

To be classified as “floodlamps”, lamps must meet the following criteria:

- The lamp shape must be either BR20/BR30/BR40 or R20/R30/R40 or PAR20/PAR30/PAR38 (for E and GU-24 bases) or MR11/MR16 (for GU-10 bases).

Color Appearance

To meet the specification, LED lamps shall fall within a 4-step Macadam ellipse of the 2700K or 3000K points on the Planckian Locus.

Lamps shall meet this requirement under both 25°C and 55°C ambient temperatures.

Color Consistency

Lamps of the same model number must fall within a 2-step Macadam ellipse of the average chromaticity of the tested sample.

Lamps shall meet this requirement under both 25°C and 55°C ambient temperatures.

Color Rendering

To meet the specification, LED lamps shall have a minimum color rendering index (CRI) of 90. Lamps shall have an R9 value greater than 0, measured under the same conditions as the CRI.

Lamps shall meet this requirement under both 25°C and 55°C ambient temperatures.

Light Distribution

Lamps shall meet one of the following distribution requirements:

Omnidirectional Lamps

To meet the specification, LED lamps classified as omnidirectional shall meet the specifications for omnidirectional lamps in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

The *California Quality LED Lamp Specification* shall *not* recognize “semidirectional” or “nonstandard light output” lamps as being omnidirectional lamps.

Floodlamps

All LED lamps classified as floodlamps shall meet the specifications for directional lamps in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (See Appendix A), with the following exceptions:

- The light distribution must meet the following requirements:
  - Luminous intensity shall not increase from any given angle of elevation to the next, over the range 0° to 90°, for each of the azimuthal planes.
  - Beam angle shall be between 50° and 90°. Beam angle is defined as two times the elevation angle at which the intensity falls to half the peak (center-beam) intensity.
  - At least 10 percent of the total flux (lumens) must be emitted in the 60°-90° zone.
  - Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.

Spotlights

All LED lamps classified as spotlights shall meet the specifications for “PAR shapes and low voltage MR lamps” in the ENERGY STAR Product Specification for Lamps, Version 1.0 DRAFT 2 (See Appendix A).

Semidirectional and Nonstandard Light Output Lamps

Lamps classified as “semidirectional” or “nonstandard light output” by ENERGY STAR shall not qualify as California-quality LED lamps.

Dimmability

To meet the specification, LED lamps shall be capable of continuous dimming, without flicker or noise, from 10-100 percent[22]. For these lamps, the *California-Quality LED Lamp Specification* will use the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A). Observers have different levels of sensitivity to flicker; some observers are unable to detect line frequency flicker while others detect it in their peripheral vision. Flicker testing should be conducted by observers who are flicker sensitive.

To meet the specification, LED lamps shall indicate on the exterior of the packaging the manufacturer and model number for three (3) or more compatible dimmers, with which the lamp can be operated to fulfill the requirements of the Specification.

Longevity

To meet the specification, LED lamps shall comply with the minimum lamp life requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 as shown in Appendix A, including the following:

- Lamps shall have a minimum rated life of ≥ 25,000 hours.
- Lamps to be marketed as “Commercial Grade” shall have a rated life ≥ 35,000 hours.
- All tested units shall be operational at 3,000 hours, under the ENERGY STAR tests required by this Specification.

Power Factor

To meet the specification, LED lamps shall have a power factor ≥ 0.9.

Warranty

To meet the specification, LED lamps shall carry a minimum five-year, free-replacement warranty for indoor and outdoor use in residences only (both single family and multifamily). Lamps marketed as “commercial grade” shall carry a minimum five-year, free-replacement warranty for indoor or outdoor use in any building type (both residential and nonresidential).

Future Development of This Specification

The CEC staff anticipates that for the investor-owned utilities’ 2015-2016 program cycle, this Specification will be updated. Staff expect that the update will include some or all of the following elements:

[22] Note that no technical standards exist for lamp flicker or noise. Therefore the specification relies simply on a direct visual and auditory assessment of the lamp.

- The color appearance and color consistency requirements may be tightened to a three-step ellipse or to a different requirement, based on research.
- The color rendering requirement may be changed to different CCT and R9 values, or to a different metric, based on research.
- Color change (to warmer CCTs) during dimming may be required, based on research.
- Flicker testing may be required, based on research.
- Other lighting distributions, such as spotlights.
- Other lamp bases.
- Other envelope shapes, such as globe lamps for bath bars.
- Other light sources such as OLED.
- The Specification will likely refer to the new IESNA Lighting Measurement (LM) document on the lifecycle testing of LED lamps, expected to be published in 2012 or 2013.
- Consumer needs, wants, reactions, satisfaction with LED lamps derived from market research, reports, or analyses

Future Work Needed

To improve future versions of this Specification, the Energy Commission staff supports the following research activities:

- Development of a practical measure of visual and nonvisual flicker from LEDs and other light sources, including a measure of color flicker in addition to brightness flicker.
- Development of an improved color quality metric, to be based on studies of residential consumers. Some work on color metrics is being conducted by General Electric and by NIST.
- Development (if necessary) of an LED life-testing method that emulates the power quality found in residences (low power quality test) along with typical residential switching patterns and thermal environments.
- Agreement on how LED life testing (using the IES LM-80 and TM-21 methods) should account for early failure and midlife failure of LED sources. These methods do not provide adequate guidance on how to include failure data in L50 and L70 estimates.
- Development of a standard for color shift of LEDs when they are dimmed, to replicate the color shift that consumers are used to for incandescent lamps.

Ongoing markets surveys and consumer research

GLOSSARY

Lighting industry terms are used in this report for which some readers may not be familiar. Lighting terminology used in this report includes the following:

"**ANSI**" is the American National Standards Institute. ANSI is a non-profit organization that oversees the development (by others) of voluntary standards in the United States. It coordinates with international bodies such as the International Electrotechnical Commission (IEC) and Commission International de l'Eclairage (CIE).

"**ANSI Standard Shapes**" are the standard lamp (light bulb) envelope shapes defined by ANSI standards. These standards ensure that lamps from many different manufacturers will physically fit within luminaires.

"**Directional lamp**" refers to an LED lamp having at least 80 percent light output within a solid angle of π(pi) steradians (corresponding to a cone with an angle of 120 degrees) and intended to function as a direct replacement for reflector lamps, including ANSI Standard Shapes classified as R, BR, ER, and PAR. LED spotlights and recessed cans are usually "directional" lamps.

> Steradian is a measure of solid angle, i.e. an angle in three dimensions. For small solid angles, the solid angle subtended by a surface from a given point is equal to the area of the surface divided by the square of the distance between the surface and the point. A complete sphere subtends 4 pi steradians.

"**Efficacy**" for lamps is defined as how many lumens (quantity of light) are delivered for each watt of electricity that is consumed. This is analogous to miles per gallon for a car.

"**General service lamp**" refers to lamps used to satisfy a wide range of non-specialized, primarily residential lighting applications that have traditionally been serviced by general service incandescent lamps. The Federal Energy Information and Security Act of 2007 defines general service lamps as typically designed for a light output between 310 and 2600 lumens and capable of operating at a voltage range at least partially within 110 and 130 volts. Examples include incandescent A-lamps, compact fluorescent lamps, and screw-based LED lamps.

"Goniophotometer" refers to a device used for measurement of the light emitted from an object at different angles. The use of goniophotometers has been increasing in recent years with the introduction of LED-light sources, which are mostly directed light sources, where the spatial distribution of light is not homogeneous.

"**Integrated lamp**," when used for LED lamps, refers to an LED device with an integrated driver and a standardized base that is designed to connect to the electrical branch circuit via a standardized lampholder/socket. Ffor example, replacement of incandescent lamps with screw-base LED lamps. Integrated LED lamps can be designed for a variety of input voltages, but this Specification covers only those lamps designed to work at line voltage (120V).

"**Lamp**" refers to the source that creates optical radiation, also known as a "light bulb".

"**Luminaire**" refers to the housing within which the lamp is held, which provides mechanical support and electrical power to the lamp, and reflects or diffuses the light. This is also referred to as a "light fixture "in commercial applications. Many consumers refer to luminaires as "lamps", e.g., "floor lamps" or "desk lamps".

"**Macadam ellipse**" refers to the region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse. The contour of the ellipse therefore represents the just noticeable differences of chromaticity.

"**Omnidirectional lamp**," when used for LED lamps, refers to a lamp intended to function with isotropic light distribution (that is, to distribute light evenly in all directions), and intended to function as a direct replacement for incandescent A-lamps, including ANSI Standard Shapes classified as A, B, C, F, G, P, PS, S, and T.

"**Planckian Locus**" refers to the path or locus that the color of an incandescent black body would take in a particular chromaticity space as the blackbody temperature changes. It goes from deep red at low temperatures through orange, yellowish white, white, and finally bluish white at very high temperatures.

"**Solid-state lighting (SSL)**" is used by ENERGY STAR to mean LED. As used by ENERGY STAR, the term "solid-state" refers to the fact that the light is produced by solid-state electroluminescence, (that is, as a direct result of the passage of electricity through a semiconductor). This differs from fluorescence (used in fluorescent lamps) and incandescence (used in incandescent lamps).

APPENDIX A

COMPARISON OF PROPOSED VOLUNTARY CALIFORNIA QUALITY LED LAMP SPECIFICATION TO ENERGY STAR PRODUCT SPECIFICATION FOR LAMPS, VERSION 1.0, DRAFT 2

These tables show a detailed comparison between the *Proposed Voluntary California Quality LED Lamp Standard* (left column) and the ENERGY STAR requirements (Version 1.0, Draft 2). For easy comparability, the tables are ordered according to the structure of the ENERGY STAR Draft 2 requirements (not according to the structure of this staff report); the voluntary requirements of the California-Quality Specification are shown in the left column, while the ENERGY STAR requirements are shown in the right column. The ENERGY STAR requirements have not yet been finalized.

This section should not be quoted as being the proposed Specification itself. This is merely an informative appendix. For the text of the Specification see Chapter 3.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Application

California Quality LED Lamps Specification applies only to LED Lamps.	Applies to compact fluorescent and Solid State Lighting.

Specification Scope and Lamp Classification

Same as ENERGY STAR Draft 2. California EXCEPTIONS: 1. The California Specification uses a reduced list of allowable lamp bases. 2. Semi-directional lamps and decorative lamps shall not qualify as California Quality LED Lamps. 3. Lamps not meeting additional California Omnidirectional requirements in this staff report shall not qualify as Omnidirectional California Quality LED Lamps. 4. Defines an additional lamp type: "floodlamp", which must meet the ENERGY STAR requirements for directional lamps, along with additional photometric requirements.	Screw Bases: E26, E26d, E17, E12. Multiple pin bases: GU-24, GU10, GU5.x, GX5.3. ANSI Standard Shape Directional R, BR, MR, PAR ANSI Standard Shape Omnidirectional A, BT, G, P, PS, S, T. Decorative B, BA, C, CA, F.

California Quality LED Lamps	**ENERGY STAR Version 1.0, DRAFT 2**

Effective Date

As a voluntary Specification immediately upon approval of this Staff Report by the California Energy Commission.	Still to be determined by ENERGY STAR in accordance with information in Draft 2.

Future Specification Revisions

The California Energy Commission reserves the right to change the California Quality LED Lamp Specifications, including adopting selected provisions from Draft 2, or selected provisions from later version of the ENERGY STAR Specifications.	EPA reserves the right to change the ENERGY STAR specifications.

Definitions

Same as ENERGY STAR Draft 2. California ADDITION: An additional light distribution (“floodlamp”) is defined in the Light Distribution section.	ENERGY STAR definition for Decorative Lamps: Lamps with a lamp shape B, BA, C, CA, DC, and F as defined in ANSI C79. 1-2002.

Test Criteria

Same as ENERGY STAR Draft 2	Still to be determined by ENERGY STAR in accordance with information in Draft 2.

Product Qualification

Same as ENERGY STAR Draft 2.	Product variations as listed in Draft 2.

Methods of Measurement and Reference Documents

Same as ENERGY STAR Draft 2.	As listed in Draft 2.
California Quality LED Lamps	**ENERGY STAR Version 1.0, DRAFT 2**

Luminous Efficacy Requirements—All Lamps

<table>
<tr><td rowspan="9">Luminous Efficacy Requirements same as ENERGY STAR Draft 2. California EXCEPTIONS:

1. Semi-directional lamps shall not qualify as California Quality LED Lamps.
2. Lamps not meeting additional California Omnidirectional requirements shall not qualify as Omnidirectional California Quality LED Lamps.</td><td colspan="2">Luminous Efficacy Requirements: All Lamps</td></tr>
<tr><td>Lamp Input Power (Watts)</td><td>Lamp Efficacy (initial lm/W)</td></tr>
<tr><td>Omnidirectional <10</td><td>55</td></tr>
<tr><td>Omnidirectional ≥10</td><td>60</td></tr>
<tr><td>Directional <10</td><td>40</td></tr>
<tr><td>Directional ≥10</td><td>45</td></tr>
<tr><td>Decorative <10</td><td>45</td></tr>
<tr><td>Decorative ≥10</td><td>50</td></tr>
<tr><td colspan="2">Methods of Measurement and Reference Documents as listed in Draft 2 for SSL.</td></tr>
</table>

Supplemental Testing Requirements for Luminous Efficacy same as ENERGY STAR Draft 2.	**Supplemental Testing** For dimmable/2-way/3-way products, measurements shall be made at the highest wattage setting listed for the model. Sample Size: 10 units per model: 5 units tested base-up and 5 units tested base-down unless the manufacturer restricts specific use or position. If position is restricted, all units shall be tested in restricted position. Passing Test: Average of unit values shall meet the requirement, and ≥9 units individually shall meet the required value. If units are tested both base-up and base-down, averages shall be calculated for both subsets, and the efficacy shall be the lesser of the two averages.

Light Output Requirements—All Lamps

Light Output Requirements same as ENERGY STAR Draft 2.	Light Output Requirements as listed in Draft 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Elevated Temperature Light Output Ratio—All Lamps

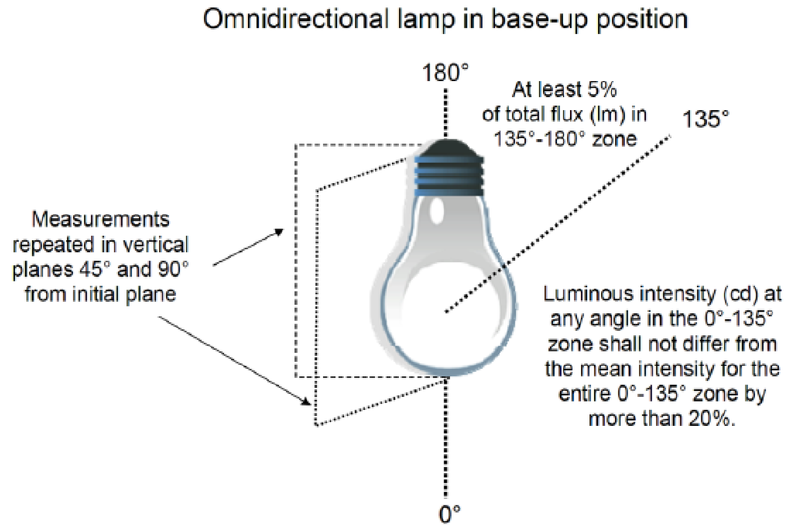
Elevated Temperature Light Output Ratio same as ENERGY STAR Draft 2.	Elevated Temperature Light Output Ratio as listed in Draft 2. Lamp shall maintain ≥ 90% of initial rated light output (total luminous flux) when tested in the elevated temperature condition.

Center Beam Intensity Requirement—PAR and MR Shapes

California EXCEPTION: 1. PAR and MR lamps are not required to meet minimum requirements for Center Beam Intensity.	Center Beam Intensity Requirements as listed in Draft 2.

Luminous Intensity Distribution Requirements—Omnidirectional Lamps

Luminous Intensity Distribution Requirements for Omnidirectional Lamps same as ENERGY STAR Draft 2.	Lamp luminous intensity distribution shall emulate that of the referenced incandescent lamp as follows: • Each luminous intensity measured value (candelas) shall vary by no more than 20% from the average of all measured values. • No less than 5% of total flux (lumens) shall be emitted in the 135° to 180° zone. See diagram below. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

ENERGY STAR Draft 2 Luminous Intensity Distribution Diagram for Omnidirectional Lamps

Source: ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

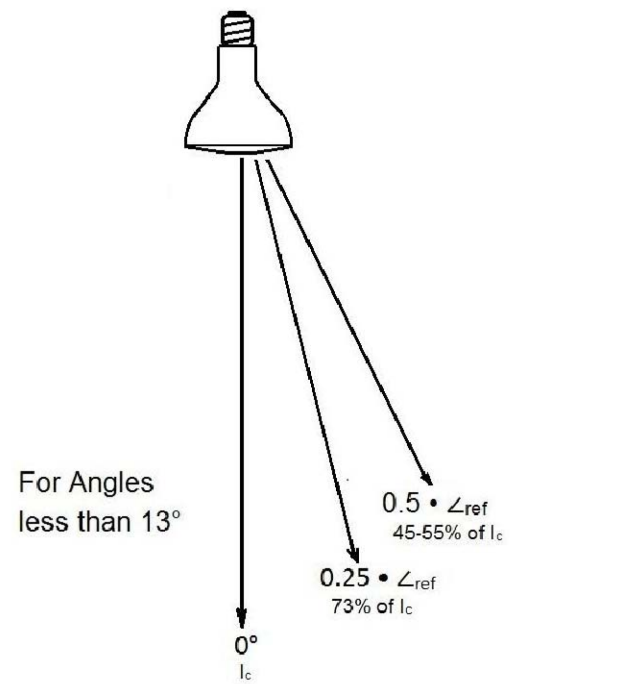
California Quality LED Lamps	**ENERGY STAR Version 1.0, DRAFT 2**

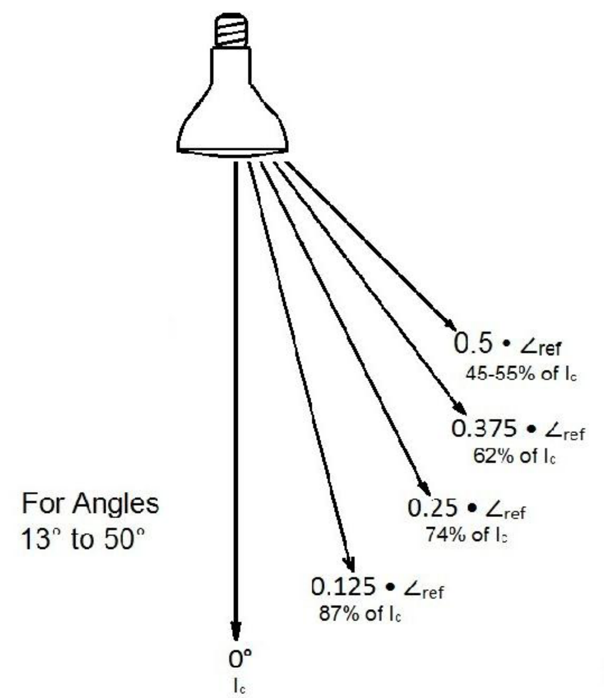
Luminous Intensity Distribution Requirements—PAR and MR lamps

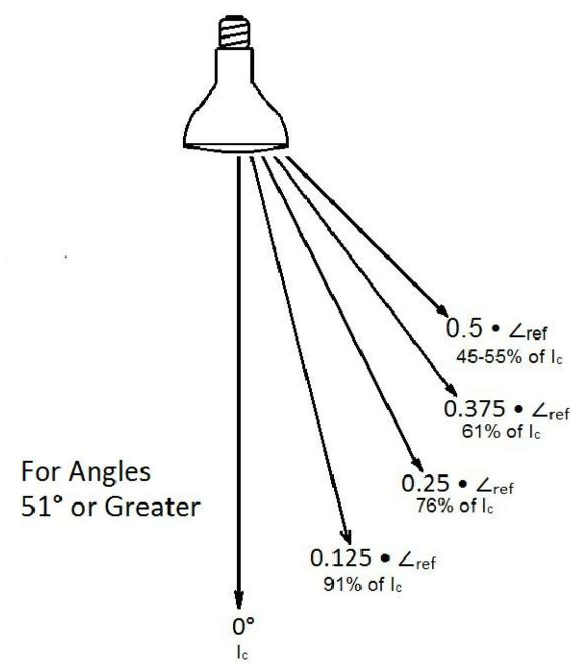
The California Quality Specification recognizes "floodlamp"-style lamps in addition to "spotlight"-style lamps. As such, in addition to the ENERGY STAR distribution requirements for PAR and MR lamps, the following alternative requirements exist for PAR and MR lamps that are classified as "floodlamps": • Luminous intensity shall not increase from any given angle of elevation to the next, over the range 0° to 90°, for each of the azimuthal planes. • Beam angle shall be between 50° and 90°. Beam angle is defined as two times the elevation angle at which the intensity falls to half the peak (center-beam) intensity.	Lamp luminous intensity distribution shall emulate that of the referenced incandescent lamp, including its nominal beam angle ("reference angle" or $\angle_{ref}$), as follows: Measured on two rotational planes 90° from each other around and through the beam axis, lamp luminous intensity within each plane shall measure no less than 45% and no greater than 55% of the center beam intensity (I_c) on each edge of the beam ($0.5 \bullet \angle_{ref}$). For reference angles less than 13°, on each side of the beam axis at ($0.25 \bullet \angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 73% of I_c.

• At least 10 percent of the total flux (lumens) must be emitted in the 60°-90° zone. • Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.	For reference angles of 13° to 50°, on each side of the beam axis: • at (0.125 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 87% of I_c ; and, • at (0.25 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 74% of I_c ; and, • at (0.375 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 62% of I_c. For reference angles 51° or greater, on each side of the beam axis: • at (0.125 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 91% of I_c ; and, • at (0.25 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 76% of I_c ; and, • at (0.375 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 61% of I_c. Comparing the two rotational planes, each of the corresponding aforementioned values shall not vary by more than 20%. See diagrams on next page. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

ENERGY STAR Draft 2 Luminous Intensity Distribution Diagrams for Directional Lamps







California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Correlated Color Temperature (CCT) Requirements—All Lamps

Correlated Color Temperature (CCT) Requirements same as ENERGY STAR Draft 2. California Exception: • Only lamps with correlated color temperatures of 2700K and 3000K are recognized.	Correlated Color Temperature (CCT) Requirements: SSL. Lamps shall meet one of the following nominal CCT's: 1. 2700K 2. 3000K 3. 3500K 4. 4000/4100K 5. 5000K Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 of SSL.

Color Rendering Requirements—All Lamps

Color Rendering Requirements shall comply with the California Quality LED Lamp Specification: • Lamps shall have color rendering index ≥ 90, and $R_9 > 0$. Methods of Measurement, Reference Documents and Supplemental Testing same as Draft 2.	Lamps shall have color rendering index ≥ 80, and $R_9 > 0$. Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 of SSL.

Color Maintenance Requirements—All Lamps

Color maintenance requirements same as ENERGY STAR Draft 2. Methods of Measurement, Reference Documents and Supplemental Testing same as Draft 2.	Lamp change in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation, shall be within a total distance of 0.007 on the CIE 1976 u'v' diagram. Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 of SSL.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Color Angular Uniformity Requirements—Floodlamps and Spotlights Only

Color Angular Uniformity Requirements same as ENERGY STAR Draft 2.	Variation of chromaticity across the field angle of the lamp shall be within a total distance of 0.004 from the weighted average point on the CIE 1976 (u'v') diagram. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Lumen Maintenance and Rated Life Requirements

Lumen Maintenance Requirements same as ENERGY STAR Draft 2	Lamp shall maintain 80% of initial lumen output at 40% of rated life. Lamp shall maintain minimum percentage of 0-hour light output after completion of the test duration corresponding to lamp's life claim (hours to 70% lumen maintenance or L70) per the table(s) below. Lamp may earn optional early interim qualification after 3,000 hours, with a rated life claim ≤ 35,000 hours, per the provisions below. Lamps to be marketed as commercial grade shall satisfy requirements for no less than 35,000 hour rated life claims. (Table same as Draft 2). **For Extended Lifetime Claims:** For lamp life claims > 25,000 hours, lamp shall maintain ≥ 91.5% of 0-hour light output after completion of the test duration corresponding to lamp's life claim per the table below. (Table same as Draft 2). **To Qualify For Early Interim Qualification After 3,000 Hours**: Lamp shall maintain minimum

	percentages of 0-hour light output corresponding to the lamp's life claim per the table below, and shall meet all other requirements in this specification. A lumen maintenance projection calculation using the applicable LM-80-08 test report for the employed LED package/module/ array model (–device‖), the in situ temperature of highest temperature TMPLED, and the forward drive current applied to each device shall support a rated lumen maintenance life greater than or equal to the lamp rated life value to be claimed on product packaging. (Table same as Draft 2). Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 for SSL.

Rated Life Requirements—All Lamps

Rated Life Requirements same as ENERGY STAR Draft 2 for SSL.	Decorative lamps shall have a rated life ≥ 15,000 hours. All other lamps shall have a rated life of ≥ 25,000 hours. Lamps to be marketed as commercial grade shall have a rated life ≥ 35,000 hours. All tested units shall be operational at 3,000 hours. ≥ 90% of the tested units shall be operational at 6,000 hours. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Rapid Cycle Stress Test—All Lamps

Rapid Cycle Test Requirements same as ENERGY STAR Draft 2.	Lamp shall survive cycling once per hour of rated life, at 5 minutes on, 5 minutes off, for no more than 15,000 cycles. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Electrical Safety Requirements—All Lamps

Electrical Safety Requirements same as ENERGY STAR Draft 2.	Lamp shall comply with ANSI/UL 1993-2009, ANSI/UL 8750-2009 and ANSI/UL 8750-2009 as applicable. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Power Factor Requirements—All Lamps

All California Quality LED Lamps shall have a power factor ≥ 0.9.	Lamp shall have a power factor ≥ 0.7 for residential applications, or ≥ 0.9 if marketed as commercial grade. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Operating Frequency Requirements—All Lamps

Operating Frequency Requirements same as ENERGY STAR.	Still to be determined in accordance with Draft 2.

Start Time Requirements—All Lamps

Start Time Requirements same as ENERGY STAR Draft 2.	Lamp shall remain continuously illuminated within one second of application of electrical power. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Dimming Requirements—All Lamps

All California Quality LED lamps shall be capable of continuous dimming, flicker and noise free, from 10-100 percent. For these lamps, the proposed Specification will use the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (See Appendix A). • California Quality LED Lamps shall indicate on the exterior of the packaging the manufacturer and model number for three (3) or more compatible dimmers, with which the lamp can be operated to fulfill the requirements of the Specification.	All Lamps Marketed as Dimmable: Lamp shall meet each of the following requirements if noted as capable of dimming on the lamp, its base or packaging, product literature or point-of-purchase materials, either printed or electronic: • Dimming level: TBD. • Flicker: TBD. • Audible noise: TBD. • Compatibility: TBD. • Methods of Measurement and Reference Documents: TBD. • Supplemental Testing: TBD. The above criteria are yet to be determined by ENERGY STAR in accordance with information in Draft 2.

Transient Protection Requirement—All Lamps

Transient Protection Requirement for All Line Voltage Lamps same as ENERGY STAR Draft 2.	Lamp shall survive 7 strikes of a 100 kHz ring wave, 2.5 kV level, for both common mode and differential mode. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Noise Requirements—All Lamps

Noise Requirements for dimmable lamps same as ENERGY STAR when determined.	Noise Requirements for dimmable lamps TBD in accordance with Draft 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Lamp Toxics Reduction Requirements—All Lamps

Lamp Toxicity Reduction Requirements same as ENERGY STAR Draft 2.	Lamp Toxicity Reduction Requirements as listed in Draft 2, as applicable.

Lamp Shape Dimensional Requirements—All Lamps

All ANSI Standard Lamps same as ENERGY STAR Draft 2. California EXCEPTIONS: • The California Specification uses a reduced list of allowed lamps shapes, as shown in the staff report.	Lamp Shape Dimensional Requirements as listed in Draft 2 Methods of Measurement and Reference Documents as listed in Draft 2 Supplemental Testing as listed in Draft 2.

Lamp Thermal Requirements—All Lamps

Minimum Operating Temperature Requirements same as ENERGY STAR Draft 2.	Lamp shall have a minimum ambient operating temperature of 0°F (-18°C) or below. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Lamp Labeling, Packaging, and Warranty Requirements—All Lamps

Lamp Labeling Requirements same as ENERGY STAR Draft 2.	Each of the following shall be printed on the lamp: • Lamp manufacturer or brand name • Lamp model number as will appear on the ENERGY STAR qualifying product list. • Lamp nominal correlated color temperature including —Kelvin‖ or —K‖. • Rated wattage in watts (lamps not covered by FTC requirements). • Lamp rated lumen output in lumens (lamps not covered by FTC requirements).
Lamp Packaging Requirements same as ENERGY STAR Draft 2.	Lamp Packaging Requirements as listed in Draft 2.

Warranty Requirements All California Quality LED Lamps shall be backed by a minimum five-year warranty, from date of purchase, when rated at no less than three hours per day. Lamp packaging shall state: “Warranty: This lamp has a 5-year, free replacement warranty”, and a phone number or website address for consumer complaint resolution. The complete written warranty shall be printed on the exterior of the packaging, and be included within the lamp packaging. Manufacturer is solely responsible for honoring the warranty; intermediate parties (e.g. showrooms, electrical distributors, retailers) are not responsible for honoring warranty requirements.	Warranty per table in Draft 2 Lamp package shall state “Warranty” or “Limited Warranty”, the warranty period (in years) per the above table, and a phone number or website address for consumer complaint resolution. The complete written warranty shall be printed on packaging exterior or included within lamp packaging. [ENERGY STAR] Partner is solely responsible for honoring warranty; intermediate parties (e.g. showrooms, electrical distributors, retailers) are not responsible for honoring warranty requirements.

APPENDIX B

ANALYSIS FOR DIRECTIONALITY REQUIREMENTS

This section describes the analysis that supports the directionality requirements of this Specification. For omnidirectional lamps, the ENERGY STAR LED requirements already contain a definition of “omnidirectional” light output, but the ENERGY STAR requirements do *not* contain a definition for the type of directional output given by floodlamps that are often used in recessed can luminaires. Therefore, this analysis has two goals:

- To determine whether the ENERGY STAR definition of “omnidirectional” successfully distinguishes truly omnidirectional lamps from “snow cones”.
- To develop a luminous intensity distribution requirement for floodlamps that distinguishes these lamps from both omnidirectional lamps and narrow-beam floodlights/spotlights.

To visualize the direction of light output from each lamp, the graphs below show elevation angle vs. measured relative luminous intensity (cd/klm). Staff compared several currently available LED lamps with their incandescent equivalents. This graph is similar to the standard “polar curve” commonly used in the lighting industry, but this format provides better visual resolution of small intensity values.

Intensity can be measured either as *absolute* intensity (candelas) or *relative* intensity (candelas per thousand lumens of lamp output); of these two, relative intensity is usually the most useful because it allows lamps of different lumen outputs to be directly compared on the same scale.

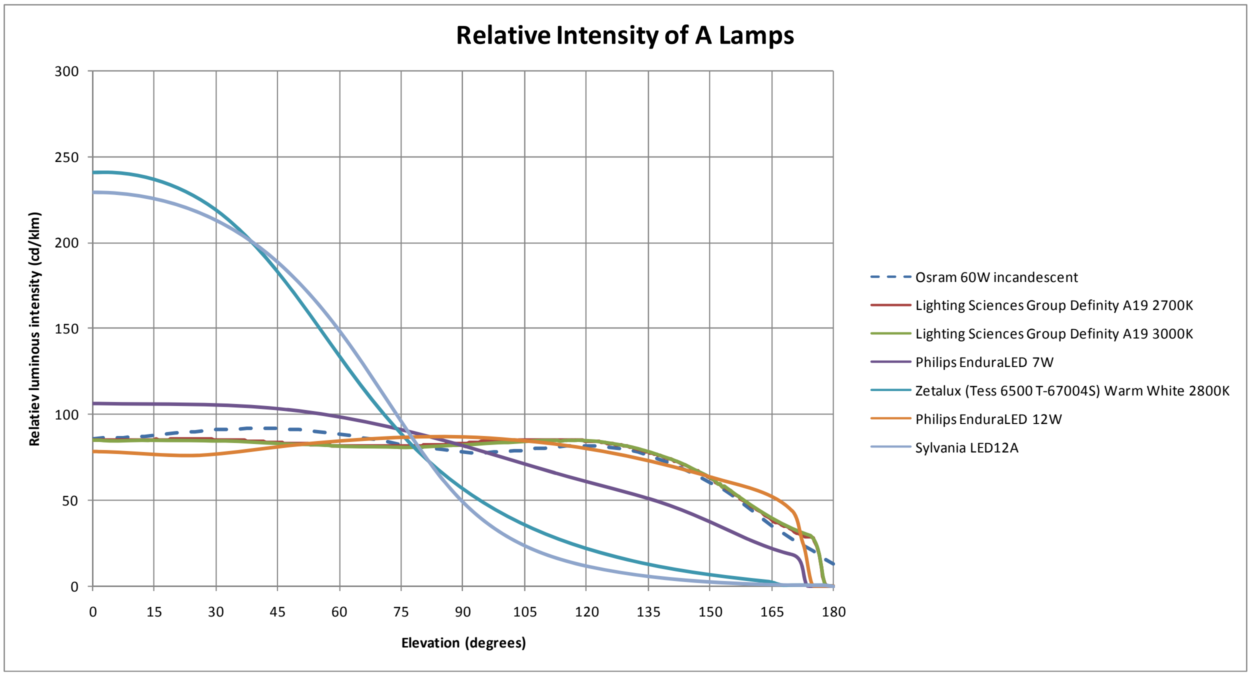
Omnidirectional Lamps

The ENERGY STAR requirement for omnidirectional lamps is as follows:

> *Products shall have an even distribution of luminous intensity (candelas) within the 0° to 135° zone (vertically axially symmetrical). Luminous intensity at any angle within this zone shall not differ from the mean luminous intensity for the entire 0° to 135° zone by more than 20%. At least 5% of total flux (lumens) must be emitted in the 135°-180° zone. Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.*

The graph below shows that several of the LED lamps tested are very similar to a reference 60W incandescent A-lamp (dashed line). The four LED lamps that closely follow the incandescent curve meet the ENERGY STAR criteria for omnidirectional. The lamp shown in purple (which gives a small amount of light backwards) follows the incandescent curve somewhat closely, but it fails the ENERGY STAR criteria because its intensity falls below the minimum allowed value at elevations above about 105 degrees. The two “snow cone” lamps fail to meet the omnidirectional criteria by a long way. Based on this analysis, the ENERGY STAR criteria distinguish omnidirectional lamps from snow cones very effectively, and the criteria can be met by commercially available lamps.

Figure 6: Relative Intensity of Various A-Lamps



Source: California Energy Commission, staff analysis conducted for this report.

Floodlamps

Since there is no ENERGY STAR definition for a floodlamp, staff analyzed the beam shapes of several different models of incandescent lamp (including a reference lamp, the GE 56W R30 flood, shown by the dashed line). The various incandescent beam shapes show that the narrower-beam spotlights have high intensities in the center of the beam and low intensities outside the half-beam angle.

The goal for the luminous intensity distribution requirements is that they should:

- Ensure that lamps do not have sudden changes in intensity at different viewing angles, i.e., they should avoid sudden cutoffs or other unexpected changes.
- Set boundaries for diffuse vs. focused light beams. A beam that is either too diffuse or too focused would not give the kind of light distribution a consumer would expect from a floodlight.
- Ensure that lamps have at least some apparent brightness when viewed at angles close to horizontal, for instance from across a room.

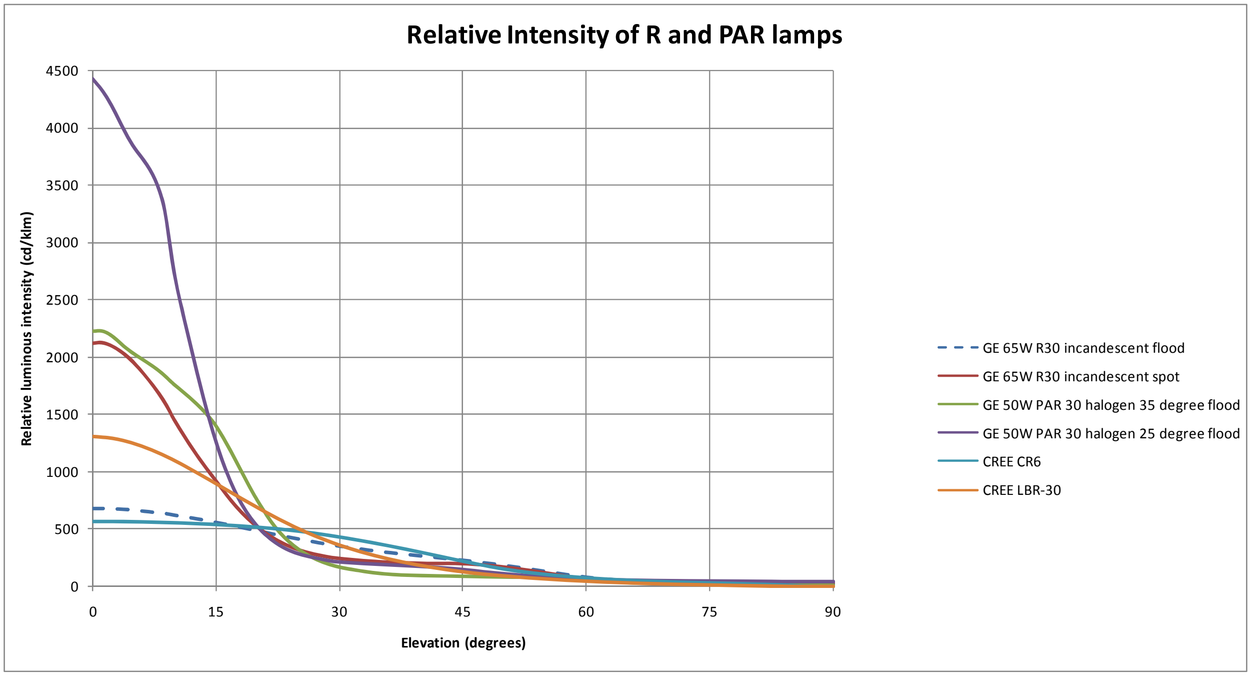
The luminous intensity requirements for floodlamps are therefore in four parts:

- Luminous intensity shall not increase from any given angle of elevation to the next, over the range 0° to 90°, for each of the azimuthal planes.
- Beam angle shall be between 50° and 90°.

- At least 10 percent of the total flux (lumens) must be emitted in the 60°-90° zone.
- Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.

Two of the lamps in the graph below meet these requirements: the reference incandescent and the CREE CR6. The CREE LBR-30 falls just outside the acceptable beam angle range.

Figure 7: Relative Intensity of Various R and PAR Lamps



Source: California Energy Commission, staff analysis conducted for this report.

APPENDIX C

AVAILABLE RESEARCH ON CONSUMER PERCEPTIONS AND PREFERENCES FOR RESIDENTIAL LAMPS

Appendix under development

APPENDIX D

CODES AND STANDARDS CONTEXT

Energy Independence and Security Act of 2007 (EISA)

The Energy Independence and Security Act of 2007 (EISA) − passed by Congress and signed by President George W. Bush − created new energy efficiency standards for general service lamps. The law is designed to reduce energy use and greenhouse gas emissions and make the United States less dependent on foreign sources of energy. The entire country started phasing in this standard on January 1, 2012. EISA allows California to implement the national standard on a timeline that starts one year earlier.

The EISA lamp requirements, as implemented in California, are shown in the table below:

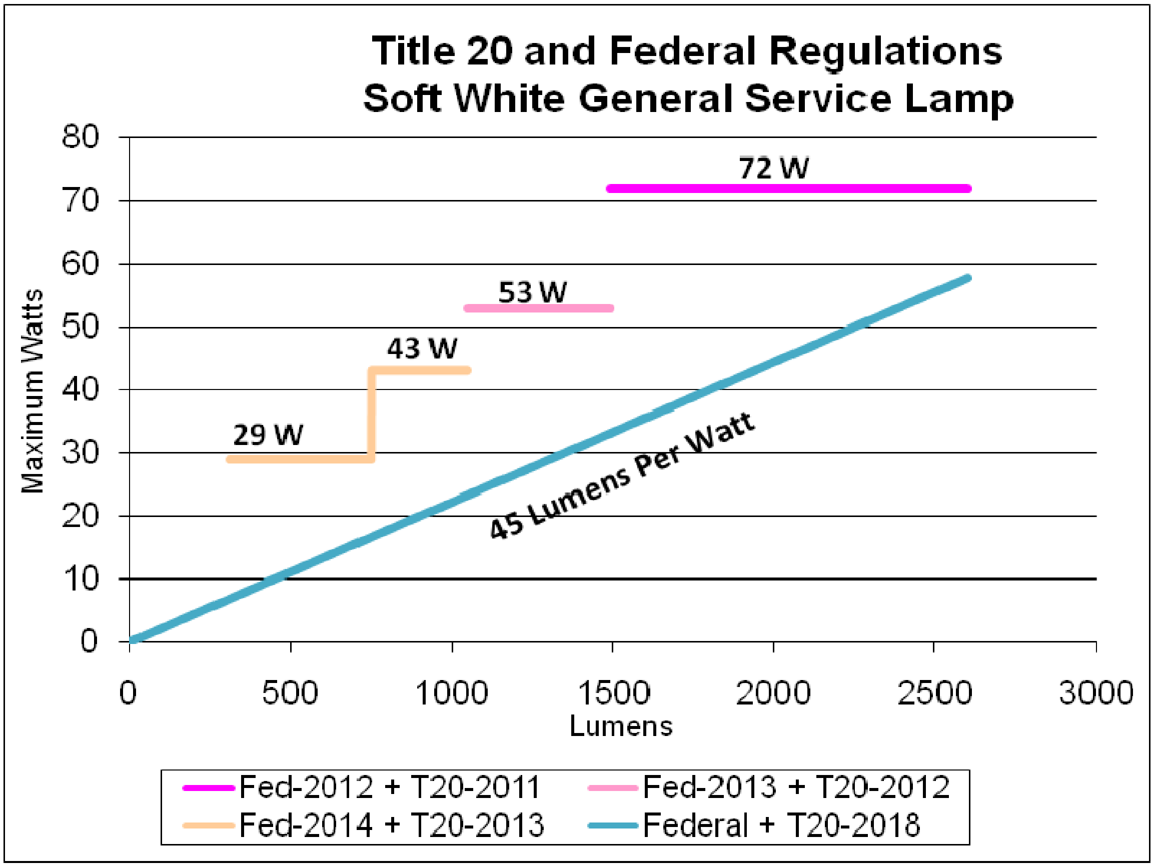
Figure 8: EISA Requirements for General Service Lamps in California

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Life	California Effective Date	What this means relative to traditional wattage lamps
1490-2600	72	1,000	1/1/2011	What was once a 100 watt lamp must provide the same light output but consume no more than 72 watts.
1050-1489	53	1,000	1/1/2012	What was once a 75 watt lamp must provide the same light output but consume no more than 53 watts.
750-1049	43	1,000	1/1/2013	What was once a 60 watt lamp must provide the same light output but consume no more than 43 watts.
310-749	29	1,000	1/1/2014	What was once a 40 watt lamp must provide the same light output but consume no more than 29 watts.

Source: California Appliance Efficiency Regulations, 2010.

These standard levels can generally be met by halogen incandescent lamps, as well as CFLs and LEDs. Starting on January 1, 2018, the EISA requirements for all general service lamps will increase further to a minimum efficacy of 45 lumens per watt. It is not clear whether manufacturers will make halogen incandescent lamps to meet this second tier of EISA standards in 2018. Regardless, it is anticipated that the EISA general service lamp requirements are going to significantly increase consumer demand for quality, high-efficacy lamps.

Figure 9: Power Consumption and Luminous Flux Requirements for General Service Lamps in Title 20 and EISA



Source: California Appliance Efficiency Regulations, 2010; Section 1605; Federal Energy Independence and Security Act, 2007, Section 321.

There are already California regulations on lamps that have GU-24 bases. GU-24 is an ANSI-defined pin-based socket designed to replace the Edison screw-based socket for certain applications. The California Appliance Efficiency Regulations (Title 20) do not allow any incandescent GU-24 base lamps, luminaires with GU-24 sockets that are rated for incandescent lamps, or adaptors that convert GU-24 sockets to screw-based sockets to be sold or offered for sale in California. This means that all GU-24 lighting products sold or offered for sale in California must be high-efficacy products such as LED lamps, self-ballasted fluorescent lamps, or self-ballasted high-intensity discharge (HID) lamps.

California Public Utilities Commission

The California Public Utilities Commission's (CPUC) *Decision Providing Guidance on 2013-2014 Energy Efficiency Portfolios and 2012 Marketing, Education, and Outreach*[23] supports the establishment of minimum California performance specifications for LED lamps that will

23 California Public Utilities Commission. *Decision Providing Guidance on 2013-2014 Energy Efficiency Portfolios and 2012 Marketing, Education, and Outreach (Decision 12-05-015)*. Page 227. May 10, 2012.

ensure ratepayer funds support only quality products that consumers will desire. The development and implementation of this proposed Specification will be necessary to avoid the prior experience with CFLs, in which early rebates for CFLs incentivized inferior products that permanently hampered public perception of this product.

The CPUC's plans for the investor-owned utilities (IOUs) call for them to shift their incentive funding from basic compact fluorescent lamps to more advanced products, such as dimmable compact fluorescent lamps and LEDs. At the same time, CPUC plans a phase-out of basic compact fluorescent lamp incentives to consumers. As indicated in the *Draft 2011 California IOU Potential Study*, the technical potential for LED lighting, starting in 2013, is significantly higher than the current market potential.

ENERGY STAR

The proposed Specification is constructed to allow LED lamp manufacturers to meet both the ENERGY STAR and the California Quality LED Lamp Specification. An LED lamp that meets the proposed Specification for color quality, dimmability, longevity, and light distribution can also meet the remaining ENERGY STAR Product Specification for Lamps, thus meeting both requirements.

Appendix A compares the proposed Specification to the ENERGY STAR Product Specification for Lamps, Version 1.0, and DRAFT 2.

APPENDIX E

COMPACT FLUORESCENT LIGHTING IN AMERICA: LESSONS LEARNED ON THE WAY TO MARKET

In 2006, Pacific Northwest National Laboratory authored a report for the U. S. Department of Energy, on the lessons learned from the introduction of CFLs into the U. S. market[24]. One section of this report dealt specifically with lessons that could be applied to the introduction of new technologies, for example, LEDs. The report contained a summary of those lessons, which is presented below in the original language of the report with additional explanations.

Application to LED and Other New Lighting Technologies

- Much consumer research is needed to determine what the consumer does and does not know before the initial product launch so that the launch is done right the first time.
- Accurate incandescent equivalency on packaging is critical.
- Rely as much as possible on retailers for customer education. Product packaging can also be a very powerful way to convey product benefits.
- Industry collaboration, perhaps through NEMA, would be helpful, though difficult to achieve given the large number of manufacturers.
- Coordinate with energy efficiency programs once products are available but don't start before products are ready [for reliable mass-production at high volume].
- Don't rely on giveaways and coupons or other programs that confuse consumers about the actual retail price [i.e., sales information should show the original and rebated price].
- Avoid market introduction programs that distribute products outside normal retail channels, for example, utility mail-order programs.
- Performance claims must be accurate. Don't launch a product until performance issues are ironed out.
- Initial education and performance issues will be more difficult to iron out if many manufacturers are involved in the initial introduction of LEDs.
- Pricing is critical but tricky − low enough to encourage consumer demand, high enough to generate profit for the retailer and manufacturer.
- Education of both consumers and retailers is critical.
- Understand that many people will not try a new product until price drops to a range near that of existing products providing similar functionality.
- Niche marketing is the best approach for now [i.e., during early market penetration].

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24 Department of Energy and Pacific Northwest National Laboratory, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*.